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## Research Paper

# Identifying Sustainable and Efficient Broiler Farms in the Light of Energy Use Efficiency and GHG Emission Reduction: Data Envelopment Analysis Approach

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**Abstract:** This study used a non-parametric method in determining the efficiency of farmers, discriminate efficient farmers from inefficient ones, identify wasteful uses of energy in order to optimize the energy inputs for broiler production, investigate the effect of energy optimization on greenhouse gas (GHG) emission and the actual total

amount of GHG emission compared to the optimum quantity. A total sample size of 55 broiler farmers were selected from Kaduna State of Nigeria through a multi-stage sampling technique. Total energy used in various operations during broiler production was 77916.14 MJ (500 birds)<sup>-1</sup>. Results revealed that 63% of producers were technically efficient, while 43 producers under pure technical efficiency (PTE) were identified as efficient (79.6%). The mean values of technical efficiency (TE), PTE and scale efficiency (SE) of farmers were observed to be 0.976; 0.993 and 0.983, respectively. Further, 1.38% [1071.54 MJ (500 birds)<sup>-1</sup>] of overall input energies can be saved if the performance of inefficient farms rose to a high level. The study concludes that the total GHG emission can be reduced to the value of 981.08 Kg CO<sub>2</sub>eq by energy optimization.

**Keywords:** GHG emission, Efficient, Sustainable, Energy, Broiler, Data envelope analysis (DEA)



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## Introduction

The Brundtland Commission visualizes that, 'sustainable agriculture should involve the successful management of resources to satisfy the changing human needs while maintaining or enhancing the quality of environment and conserving natural resources (IPCC, 2007). Sustainable agriculture management endeavours to tackle many serious problems affecting world food production, high energy costs, loss of

productivity, depletion of fossil resources, low farm incomes and risk to human health and wildlife habitats. However, it is a systematic approach to understand the complex interaction within agricultural ecologies. Gasses that cause greenhouse effects are for the most part natural compounds- water vapour, CO<sub>2</sub>, methane and nitrous oxide that keeps the earth habitable. But human activity is increasing the concentration of

these and other gasses. The trend, if continues, is expected by atmospheric scientists to lead to global climate change with uncertain but potentially grave long-term effects. The level of sophistication in socio-economic assessments of climate change impacts is still rather modest. Most available damage estimates are concerned with the impact of an equilibrium climate change associated with doubling of the pre-industrial CO<sub>2</sub> concentration of all greenhouse gasses. This means that if CO<sub>2</sub> occurred now, it would impose much damage on the world economy, particularly on vulnerable sectors including agriculture, human mortality and natural ecosystems.

Chicken still remain the cheapest source of protein available for human consumption, but it cannot tolerate a wide range of climatic variations which affects its production and reproduction (Nayak *et al.*, 2015). Menquesha (2011) reported the complementarily attribute of climate change and animal production to each other always, thus its effect on livestock and poultry production all over the globe is witnessed. The production and reproduction of poultry is affected by various factors *viz.* feeding, management, disease control, stock density, housing, climate, sire effect, hatch effect etc.

The obstacles posed by climate change to poultry broiler production fit broadly into one of the two categories: loss of productivity or increasing costs (Anon., 2009). Olanrewaju *et al.* (2010) reported that when ambient temperature peak, the energy or feed consumption needs of chickens is higher than when the environment is thermo-neutral. Furthermore, they posited that major losses due to a less efficient conversion of feed to meat, detrimentally impacts on poultry health and productivity. Thus, it is obvious that climate change

## Methodology

Kaduna State of Nigeria is located between latitudes 9° 08' and 11° 07'N and longitudes 6° 10' and 8° 48'E, with a land mass of about 45,567 km<sup>2</sup> and an estimated population of 6,066,562. Agriculture constitutes the largest occupation of

has emerged as a great challenge for poultry industries to sustain the level of production.

Research has generated information and techniques to deal with most of these factors except the climate change in order to maximize production. Babinszky *et al.* (2011) reported that there was a consensus among the poultry farmers that poultry keeping is an excellent tool in poverty alleviation due to its quick turnover and low investment. Adesiji *et al.* (2013) called for an improvement in this livestock sub-sector so as to create the needed opportunity for the development of the weaker section of the society.

Efficient use of agricultural product energies helps to achieve increased production, productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural areas (Heidari, 2011). According to literature, the only study conducted on energy optimization in broiler production using Data envelopment analysis (DEA) was by Heidari (2011); with no effort of investigating effect of energy optimization on GHG emission in broiler production, thus, making this present study first of its kind. However, literature revealed recent studies which used DEA to estimate GHG emissions in crops production *viz.* Pishgar-Komleh *et al.* (2012), Pishgar-Komleh *et al.* (2013), Mohammadi *et al.* (2013), Khoshnevisan (2013a), Khoshnevisan (2013b), Qasemi-Kordkheili and Nabavi-Pelesaraei (2014), Nabavi-Pelesaraei *et al.* (2014), Sadiq *et al.* (2015), Sadiq *et al.* (2016). In the present study, the same methodology was adopted for broiler farms in Kaduna State, with the objectives to specify energy use for broiler production, segregate efficient farmers from inefficient ones, identify wasteful uses of energy inputs and investigate the effect of energy optimization on GHG emission in broiler production.

the people with many citizens participating in small scale arable crop farming and animal husbandry. A multi-stage sampling technique was used for the study. Firstly, five local government areas (LGAs) *viz.* Kaduna North, Kaduna South, Kachia, Zaria and

Makarfi were purposively selected due to high intensity of poultry production; followed by stratification of poultry producers into broilers and layers in each selected LGAs, and then random selection of 11 respondents from boiler strata in each selected LGAs, thus, given a total sample size

of 55 broiler farmers. However, only 54 valid questionnaires were retrieved and subsequently treated. Data were elicited viz. pre-tested questionnaire coupled with interview schedule, and subsequently subjected to DEA analytical technique.

Table 1. Equivalentents for various sources of energy

| Items                | Unit           | Equivalent MJ |
|----------------------|----------------|---------------|
| Human Labour         | Man-hour       | 1.96          |
| Chick                | Kg             | 4.56          |
| Broiler              | Kg             | 4.56          |
| Manure               | Kg             | 18.0          |
| Maize                | Kg             | 7.9           |
| Soyabean meal        | Kg             | 12.06         |
| Fish meal (FA)       | Kg             | 9             |
| Di calcium phosphate | Kg             | 10            |
| H <sub>2</sub> O     | m <sup>3</sup> | 1.02          |
| Petrol               | L              | 48.23         |
| Kerosene             | L              | 36.7          |
| Electric motor       | Kg             | 64.8          |
| Electricity          | kWh            | 11.93         |

Source: Heidari *et al.* (2011)

Empirical model

*Data Envelopment Analysis (DEA)*: The DEA technique builds a linear piece-wise function from empirical observations of inputs and outputs. DEA is a nonparametric approach for estimating productive efficiency based on mathematical linear programming techniques. Unlike parametric methods, DEA does not require a function to relate inputs and outputs. The DEA envelops the data in such a way that all observed data points lie on or below the efficient frontier (Coelli, 1996). The efficient frontier is established by efficient units from a group of observed units. Efficient units are those with the highest level of productive efficiency. In DEA an inefficient DMU (Decision making unit) can be made efficient either by minimizing the input levels while maintaining the same level of outputs (input oriented), or, symmetrically, by maximizing the output levels while holding the inputs constant (output oriented).

Technical efficiency (TE)

The TE can be defined as the ability of a DMU (e.g. a farm) to produce maximum output given a set of

inputs and technology level. The TE score ( $\theta$ ) in the presence of multiple-input and output factor can be calculated by the ratio of sum of weighted outputs to the sum of weighted inputs or in a mathematical expression given below (Cooper *et al.*, 2004):

$$\theta = \frac{U_1Y_{1j}+U_2Y_{2j}+\dots+U_sY_{sj}}{V_1X_{1j}+V_2X_{2j}+\dots+V_mX_{mj}} = \frac{\sum_{r=1}^s U_r Y_{rj}}{\sum_{i=1}^m V_i X_{ij}} \dots\dots \text{(Equation 1)}$$

Let the DMU<sub>j</sub> to be evaluated on any trial be designated as DMU<sub>o</sub> ( $o = 1, 2 \dots n$ ). To measure the relative efficiency of a DMU<sub>o</sub> based on a series of  $n$  DMUs, the model is structured as a fractional programming problem, and specified as Equation 2 (Cooper *et al.* 2006):

$$\text{Max: } \theta = \frac{\sum_{r=1}^s U_r Y_{ro}}{\sum_{i=1}^m V_i X_{io}} \dots\dots\dots \text{(Equation 2)}$$

$$\text{Subject to: } \theta = \frac{\sum_{r=1}^s U_r Y_{rj}}{\sum_{i=1}^m V_i X_{ij}} \dots\dots\dots \text{(Equation 3)}$$

$$U_r \geq 0, V_i \geq 0,$$

where  $n$  is the number of DMUs in the comparison,  $s$  the number of outputs,  $m$  the number of inputs,  $U_r$  ( $r = 1, 2, \dots, s$ ) the weighting of output  $Y_r$  in the

comparison,  $V_i$  ( $i= 1, 2, \dots, m$ ) the weighting of input  $X_i$ , and  $Y_{rj}$  and  $X_{ij}$  represent the values of the outputs and inputs  $Y_{rj}$  and  $X_{ij}$  for DMU $_j$ , respectively. Equation (2) can equivalently be written as a linear programming (LP) problem as Equation 3:

$$\text{Max: } \theta = \sum_{r=1}^s U_r Y_{r0} \dots\dots\dots \text{(Equation 4)}$$

subject to:  $\sum_{r=1}^s U_r Y_{rj} - \sum_{i=1}^m V_i X_{ij} \leq 0, J = 1, 2, \dots, n,$   
 $\sum_{i=1}^m U_i Y_{i0}, \text{ and } U_r \geq 0, V_i \geq 0.$

The dual linear programming (DLP) problem is simpler to solve than Equation (3) due to fewer constraints. Mathematically, the DLP problem is written in vector–matrix notation as:

$$\text{Min: } \theta = \sum_{r=1}^s U_r Y_{r0} \dots\dots\dots \text{(as in Equation 4)}$$

subject to:  $Y_\lambda \geq y_0, X_\lambda - \theta X_0 \leq 0$  and  $\lambda \geq 0$

where  $Y_0$  is the  $s \times 1$  vector of the value of original outputs produced and  $X_0$  is the  $m \times 1$  vector of the value of original inputs used by the  $o^{\text{th}}$  DMU.  $Y$  is the  $s \times n$  matrix of outputs and  $X$  is the  $m \times n$  matrix of inputs of all  $n$  units included in the sample.  $\lambda$  is a  $n \times 1$  vector of weights and  $\theta$  is a scalar with boundaries of one and zero, which determines the technical efficiency score of each DMU. Equation 3 is known as the input-oriented CCR (Charnes, Cooper and Rhodes) DEA model. It assumes constant returns to scale (CRS), implying that a given increase in inputs would result in a proportionate increase in outputs.

Pure technical efficiency (PTE)

The TE derived from CCR model, comprehend both the technical and scale efficiencies. Thus, Banker *et al.* (1984) developed a model in DEA, which was called BCC (Banker, Charnes and Cooper) model to calculate the PTE of DMUs. The BCC model is provided by adding a restriction on  $\lambda$  ( $\lambda =1$ ) in the model (Equation 4), resulted to no condition on the allowable returns to scale. This model assumes variable returns to scale (VRS), indicating that a change in inputs is expected to result in a disproportionate change in outputs.

Scale efficiency (SE)

The scale efficiency (SE) relates to the most efficient scale of operations in the sense of

maximizing the average productivity. A scale efficient farmer has the same level of technical and pure technical efficiency scores. It can be calculated as Equation 5:

$$SE = \frac{TE}{PTE} \dots\dots\dots \text{(Equation 5)}$$

The SE gives the quantitative information of scale characteristics. It is the potential productivity gained from achieving optimum size of a DMU. However, scale inefficiency can be due to the existence of either increasing return to scale (IRS) or decreasing return to scale (DRS). A shortcoming of the SE score is that it does not indicate if a DMU is operating under IRS or DRS conditions. This problem is resolvable by solving a non-increasing returns of scale (NIRS) DEA model, which is obtained by substituting the VRS constraint of  $\lambda=1$  in the BCC model with  $\lambda \leq 1$ . The IRS and DRS can be determined by comparing the efficiency scores obtained by the BCC and NIRS models; so that, if the two efficiency scores are equal, then DRS apply, else IRS prevail. The information on whether a farmer operates at IRS, CRS or DRS status is particularly helpful in indicating the potential redistribution of resources between the farmers, thus, enables them to achieve higher output.

The results of standard DEA models divide the DMUs into two sets of efficient and inefficient units. The inefficient units can be ranked according to their efficiency scores; while, DEA lacks the capacity to discriminate between efficient units; number of methods are in use to enhance the discriminating capacity of DEA. In this study, the benchmarking method was applied to overcome this problem. In this method, an efficient unit which was chosen as the useful target for many inefficient DMUs and so appears frequently in the referent sets is highly ranked.

In the analysis of efficient and inefficient DMUs, the energy saving target ratio (ESTR) was used to specify the inefficiency level of energy usage for the DMUs under consideration. Following Sadiq *et al.* (2015); Sadiq *et al.* (2016), the formula is given Equation 6:

$$ESTR (\%) = \frac{(\text{Energy saving target})}{(\text{Actual energy input})} \times 100 \dots\dots \text{(Equation 6)}$$

where energy saving target is the total amount of energy inputs reduced, which could be saved without reducing the output level. A higher ESTR percentage implies higher energy use inefficiency, and thus, a higher energy saving amount.

### GHG emissions

CO<sub>2</sub> emission coefficients of inputs were used to quantifying GHG emissions in broiler production. GHG emission was calculated by multiplying the input application rate by its corresponding emission coefficient (Table 2).

Table 2. GHG emission coefficients of inputs

| Items          | Unit | GHG coefficient (kg CO <sub>2</sub> eq. unit <sup>-1</sup> ) |
|----------------|------|--|
| Petrol         | L    | 1.85   |
| Kerosene       | L    | 1.85   |
| Electric motor | MJ   | 0.071  |
| Electricity    | kWh  | 0.608  |

Source: Lal (2004)

## Results and Discussion

### Energy use pattern in broiler production

Table 3 presents the amount of inputs, output and their energy equivalents for broiler production. The total energy consumption was 77,916.14 MJ (500 birds)<sup>-1</sup>. Feed with approximate share of 72.7% was the most energy consumed, followed by electricity. The main reason for high feeds energy consumption was that farmers were unaware about the appropriate knowledge about the proper time and amount of feeds usage, and also the

common belief that increased use of feeds energy resource will increase output.

Contribution of human labour, machinery (electric motor) and H<sub>2</sub>O in comparison with other inputs in the total input energy is negligible. However, total output energy observed in the studied area was 142,458.26 MJ (500 birds)<sup>-1</sup>; the average output of broiler and manure were 816.86 Kg and 7,707.41 Kg, respectively, per 500 birds.

Table 3. Amounts of inputs, output and their energy equivalents for broiler production

| Inputs                             | Quantity (500 birds) <sup>-1</sup> | Total energy equivalent [MJ (500 birds) <sup>-1</sup> ] | %    |
|------------------------------------|------------------------------------|---|------|
| Chicks (kg)                        | 222.33                             | 1,013.84  | 1.3  |
| Human labour (man hours)           | 78.83                              | 154.5   | 0.2  |
| Feeds (kg)                         |                                    |   |      |
| a. Maize                           | 1434.076                           | 11,329.20   | 14.5 |
| b. Soya bean meal                  | 1878.806                           | 22,658.40   | 29.1 |
| c. Fatty meal (FA)                 | 2014.079                           | 18,126.71   | 23.3 |
| d. Di-calcium phosphate            | 453.168                            | 4,531.68  | 5.8  |
| H <sub>2</sub> O (m <sup>3</sup> ) | 0.1028                             | 0.1049  | 0    |
| Petrol (L)                         | 44.63                              | 2,152.49  | 2.8  |
| Kerosene (L)                       | 13.704                             | 502.93  | 0.7  |
| Electric motor (kg)                | 3.045                              | 197.32  | 0.2  |
| Electricity (kWh)                  | 1445.847                           | 17,248.96   | 22.1 |
| Total energy input                 |                                    | 77,916.14   | 100  |
| Output                             |                                    |   |      |
| a. Broiler (kg)                    | 816.86                             | 3,724.88  |      |
| b. Manure (kg)                     | 7707.41                            | 138,733.38  |      |
| Total energy output                |                                    | 142,458.26  |      |

Source: Field survey – 2015

**Efficiency measurement of broiler farmers**

Results of farmers’ distribution based on the efficiency score obtained by the application of CCR and BCC DEA models are shown in Figure 1. Evidently, 63% (34 farmers) and 79.6% (43 farmers) from the total farmers were identified as efficient farmers under constant and variable returns to scale assumptions, respectively; implying these farms could shift on CCR and BCC frontier. Furthermore, approximately 25.9% and

20.4% of TE and PTE, respectively, had efficiency scores between 0.99 and 1.00. However, if the BCC model is assumed, only 11.1% had efficiency scores of less than 0.89, whereas if the CCR model is considered, none had efficiency score of less than 0.89. The results of returns to scale estimation indicated that all of the technically-efficient farmers (based on the CCR model) were operating at constant return to scale (CRS), indicating the optimum scale of their practices

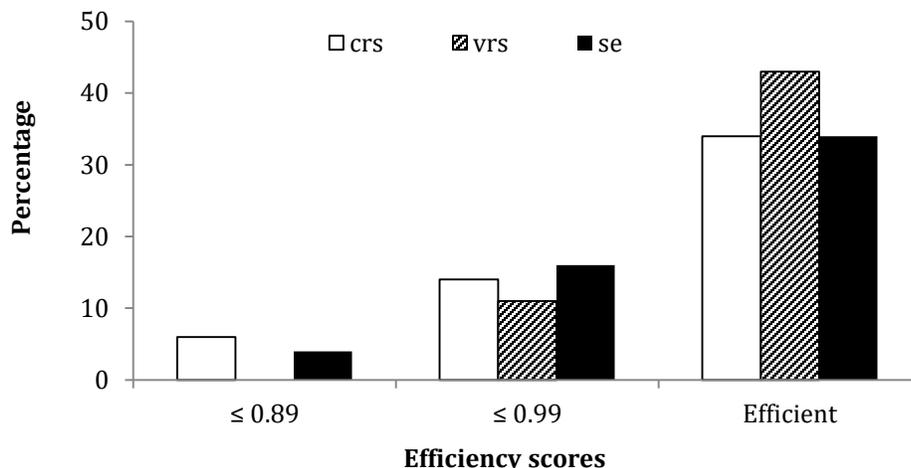


Figure 1. The percentage distribution of efficiency scores. crs = constant return to scale; vrs = variable returns to scale, se = scale efficiency

Summarized statistics for the three estimated measures of efficiency are given in Table 4. Results revealed that the average values of technical and pure technical efficiency scores were 0.976 and 0.993, respectively. The technical efficiency scores varied from 0.814 - 1.0, while pure technical efficiency scores ranged from 0.904 - 1.0. The small variation in the technical efficiency implies that all

the farmers were fully aware of the right production techniques but did not apply them properly; while mild variation in pure technical efficiency indicates that the farmers were almost rational in allocation of resources at their disposal. The average PTE provides information about the potential resource savings that could be achieved while maintaining the same output level.

Table 4. Deciles frequency distributions of efficiency scores

| Efficiency level | TE        | PTE       | SE        |
|------------------|-----------|-----------|-----------|
| ≤ 0.89           | 6 (11.1)  | 0         | 4 (7.4)   |
| ≤ 0.99           | 14 (25.9) | 11 (20.4) | 16 (29.6) |
| 1.00             | 34 (63)   | 43 (79.6) | 34 (63)   |
| Total            | 54        | 54        | 54        |
| Minimum          | 0.814     | 0.904     | 0.814     |
| Maximum          | 1.00      | 1.00      | 1.00      |
| Mode             | 1.00      | 1.00      | 1.00      |
| Mean             | 0.976     | 0.993     | 0.983     |
| SD               | 0.047     | 0.021     | 0.040     |

Source: Computed from DEAP 2.1 computer print-out. Figures in parenthesis are percentages

In the case of TE, farmers with efficiency scores of less than one, are technologically inefficient in energy use, while for PTE, farmers with less than one efficiency scores are wasting energy resources than required, indicating ample scope for target farmers to improve their operational practices in enhancing their energy use efficiency for adjustment strategy. If technical efficiency is assumed, average farmers need to increase their efficiency scores by 2.4%; the worst inefficient farmers require TE adjustment scores of approximately 18.6%, and best inefficient farmers require approximately 0.7% adjustment, respectively, to be on the frontier surface. However, if an adjustment for pure technical efficiency scores is assumed, average farmers need to reduce their energy inputs by 0.7%; worst inefficient farmers' needs approximately 9.6% input reduction, and best inefficient farmers require 0.2% input reduction, respectively, to be on the frontier surface.

Based on pure technical efficiency, 34 farmers were globally efficient and operating at the most productive scale sizes of production, while 9 farmers were locally efficient entities operating at an inferior scale sizes. The average scale efficiency score was relatively low (0.983), showing the

disadvantageous conditions of scale size. This indicates that if all of the inefficient farmers operated at the most productive scale size, about 1.7% savings in energy use from different sources would be possible without affecting the output level.

Returns to scale properties in broiler production

The BCC model includes both IRS and DRS, while NIRS model gives DRS. To determine whether a DMU has IRS or DRS, an additional test is required. The values of TE for both BCC and NIRS were calculated and their values were compared.

The same values of TE for NIRS and BCC models show that the DMU has DRS, while different values imply that the farm has IRS. Results of RTS for some selected DMUs revealed that 34 DMUs had CRS; 12 DMUs had DRS, while 8 DMUs were found to be operating at IRS (Table 5). Therefore, a proportionate increase in all inputs leads to more proportionate increase in outputs; and for considerable changes in yield, technological changes in practices are required. The information on whether a farmer operates at IRS, CRS or DRS is particularly helpful in indicating the potential redistribution of resources between the farmers, thus, enables them to achieve higher output.

Table 5. Characteristics of farms with respect to return to scale

| Scale         | No. of farms | Mean energy output |            |
|---------------|--------------|--------------------|------------|
|               |              | Broiler            | Manure     |
| Sub-optimal   | 8            | 3,438.38           | 128,025.00 |
| Optimal       | 34           | 3,753.48           | 144,158.82 |
| Super-optimal | 12           | 3,834.87           | 130,500.00 |

Source: Computed from DEAP 2.1 computer print-out

Ranking analysis of broiler production

Identifying efficient operating practices and their dissemination will help to improve efficiency not only in the case of inefficient farmers but also for relatively efficient ones, because efficient farmers obviously follow good operational practices. However, among the efficient farmers, some show better operational practices than others, therefore, discrimination need to be made among the efficient farmers while seeking the best operational practices. In order to have the efficient farmers ranked, the number of times an efficient DMU appears in a referent set was counted (Table 6).

Only efficient farms serve as peers for the inefficient farms and in this instance farms 1-2, 15-16, 17-20, 21-24, 25-26, 28-29, 31-33, 37-39, 40-41, 44-45, 47-48, 49-50, 51 and 52 are the peers. Farm 24, for example, was a peer for 7 farms making it the most comparator used farm. These efficient farms can be selected by inefficient DMUs as best practice DMUs, making them a composite DMU instead of using a single DMU as a benchmark. While the referent set is composed of the efficient units which are similar to the input and output levels of inefficient units, efficient DMUs with more appearance in referent set are known as superior

unit/spark plug in the ranking. Results of such analysis would be beneficial to inefficient farmers to manage their energy sources usage in order to attain the best performance of energy use

efficiency. However, these superior units/spark plugs can be used as reference means of dissemination of farm improvement by extension delivery services.

Table 6. Benchmarking of efficient decision making units DMUs

| DMUs | Frequency in referent set | Ranking | DMU (farm) | Frequency in referent set | Ranking |
|------|---------------------------|---------|------------|---------------------------|---------|
| F24  | 7                         | 1       | F51        | 2                         | 5       |
| F01  | 5                         | 2       | F02        | 1                         | 6       |
| F39  | 5                         | 2       | F16        | 1                         | 6       |
| F44  | 5                         | 2       | F31        | 1                         | 6       |
| F26  | 4                         | 3       | F33        | 1                         | 6       |
| F40  | 4                         | 3       | F37        | 1                         | 6       |
| F20  | 3                         | 4       | F45        | 1                         | 6       |
| F41  | 3                         | 4       | F47        | 1                         | 6       |
| F15  | 2                         | 5       | F48        | 1                         | 6       |
| F17  | 2                         | 5       | F49        | 1                         | 6       |
| F21  | 2                         | 5       | F50        | 1                         | 6       |
| F25  | 2                         | 5       | F52        | 1                         | 6       |
| F28  | 2                         | 5       |            |                           |         |
| F29  | 2                         | 5       |            |                           |         |

Source: Computed from DEAP 2.1 computer print-out

#### Performance assessment of broiler farms

Table 7 shows the peers for each farm and the weights that these peers account for. For each inefficient farm there are peers which serve as comparators against which the farm is measured. Efficient farms do not have any peers other than themselves as they are on the efficient frontier, thus defining the efficiency. It stands to reason that the weight will be unity in the case of efficient farms.

The higher the weight the more important that particular farm is, as a peer for the inefficient farm in question. This means that the inefficient farm is better off comparing itself to the peer with the highest weight in order to improve its efficiency by emulating its peers. The identification of peers is important in that the peers' production technology, in this case pollution minimizing technology, can be studied and implemented by the inefficient farms. Result shows the worst inefficient DMU (DMU22) and the best inefficient DMU (DMU12). For instance, in the case of DMU22 the composite DMU that represents the best practice or reference composite benchmark DMU is formed by combination of DMU40, DMU51, DMU17, DMU1 and DMU5.

This indicates that the DMU22 is close to the efficient frontier segment formed by these efficient DMUs, represented in the composite DMU. The selection of these efficient DMUs is made on the basis of their comparable level of inputs and output to DMU22 (Table 7). The higher value of the intensity vector  $\lambda$  for DMU40 (0.484) indicates that its level of inputs and output is closer to DMU22 compared to the other DMUs.

#### Setting realistic input levels for inefficient broiler farmers

A pure technical efficiency score of less than unity for a farmer indicates that, at present conditions, he is using energy values more than required. Therefore, it is desirable to suggest realistic levels of energy to be used from each source for every inefficient farmer in order to avert energy wastage. Table 8 presents the average energy usage in actual and optimum conditions [MJ (500 birds)<sup>-1</sup>], possible energy savings and ESTR percentage for different energy sources. It was evident that the total energy input could be reduced to 76,844.60 MJ (500 birds)<sup>-1</sup>, while, maintaining the current production levels and also assuming no other

constraining factors. Required energies for petrol, kerosene, machinery (electric motor) and electricity were 2,086, 495.55, 192.43 and 16,922.59 MJ (500 birds)<sup>-1</sup>, respectively, while

chicks, human labour, feeds and H<sub>2</sub>O energies required were 1,003.28, 151.72, 55,992.3 and 0.1046 MJ (500 birds)<sup>-1</sup>, respectively.

Table 7. Performance assessment of broiler farms

| DMUs | PTE score (%) | Benchmarks  |
|------|---------------|---|
| F22  | 90.4          | 40 (0.484), 51 (0.127), 17 (0.099), 1 (0.267), 5 (0.024)                          |
| F11  | 91.6          | 28 (0.212), 24 (0.276), 40(0.194), 26 (0.068), 39 (0.250)                         |
| F13  | 99.5          | 24 (0.143), 48 (0.004), 1 (0.190), 41 (0.459), 49 (0.034), 29 (0.059), 20 (0.111) |
| F35  | 99.5          | 24 (0.011), 20 (0.094), 29 (0.122), 44 (0.205), 39 (0.469), 1 (0.099)             |
| F12  | 99.8          | 20 (0.041), 1 (0.507), 44 (0.392), 24 (0.060)                                     |

Source: Computed from DEAP 2.1 computer print-out. Benchmarks presented are DMU numbers followed by the intensity vector  $\lambda$  for the respective DMUs (within parenthesis)

Table 8. Energy saving [MJ (500 birds)<sup>-1</sup>] from different sources if the recommendations from this study are followed.

| Input              | Actual energy used [MJ (500 birds) <sup>-1</sup> ] | Optimum energy requirement [MJ(500 birds) <sup>-1</sup> ] | Energy saving  | ESTR (%) |
|--------------------|--|---|----------------|----------|
| Chicks             | 1013.84  | 1003.28   | 10.56 (0.99)   | 1.04     |
| Human labour       | 154.5  | 151.72  | 2.78 (0.26)    | 1.8      |
| Feeds              | 56645.99   | 55992.3   | 653.69 (61)    | 1.15     |
| H <sub>2</sub> O   | 0.1049   | 0.1046  | 0.0003 (0)     | 0.29     |
| Petrol             | 2152.49  | 2086.62   | 65.87 (6.15)   | 3.06     |
| Kerosene           | 502.93   | 495.55  | 7.38 (0.68)    | 1.47     |
| Electric motor     | 197.32   | 192.43  | 4.89 (0.46)    | 2.48     |
| Electricity        | 17248.96   | 16922.59  | 326.37 (30.46) | 1.89     |
| Total energy input | 77916.14   | 76844.60  | 1,071.54       | 1.38     |

Source: Computation from DEAP 2.1 computer print-out. Values in parenthesis are percentages

Furthermore, ESTR results showed that if all farmers operated efficiently, reduction in petrol and machinery energy inputs by 3.06% and 2.48%, respectively, could be possible without affecting the output level. These energy inputs had the highest inefficiency which owed mainly to lightening of poultry huts.

Artificial lighting is important in raising the production of chickens. If the housing is lit in the cooler hours before sunrise or after sunset, the chickens are able to eat more and grow well. However, day length must not be increased during the growing period of the young chicks until just before four weeks. In order to improve the farms environment as well as reduction in consumption of petrol fuel, it is strongly suggested that the heating system efficiency be raise or replace with alternative sources of energy such as biogas, solar energy, wind, etc. Moreover, the ESTR percentage

for total energy input was 1.38%, indicating that by adopting the recommendations obtained from this study, on average, about 1.3% [1,071.54 MJ (500 birds)<sup>-1</sup>] from total input energy in broiler production could be saved without affecting the output level.

Figure 2 illustrates the distribution of saving energy from different sources for broiler production. It is evident that the maximum contribution to total saving energy is 61% from human labour. However, human labour and electricity energy inputs contributed to the total saving energy by about 91.46%. From these results it is strongly suggested that improving the usage pattern of these inputs be considered as priorities providing significant improvement in energy productivity for broiler production in the study area. Improving energy use efficiency of human labour *viz.* channelling of its excess to other sectors

is suggested to prevent wastage by inefficient farmers. Applying alternatives sources of energy such as biogas, solar energy, wind, etc. is suggested

to prevent electrical energy wastage by inefficient farmers.

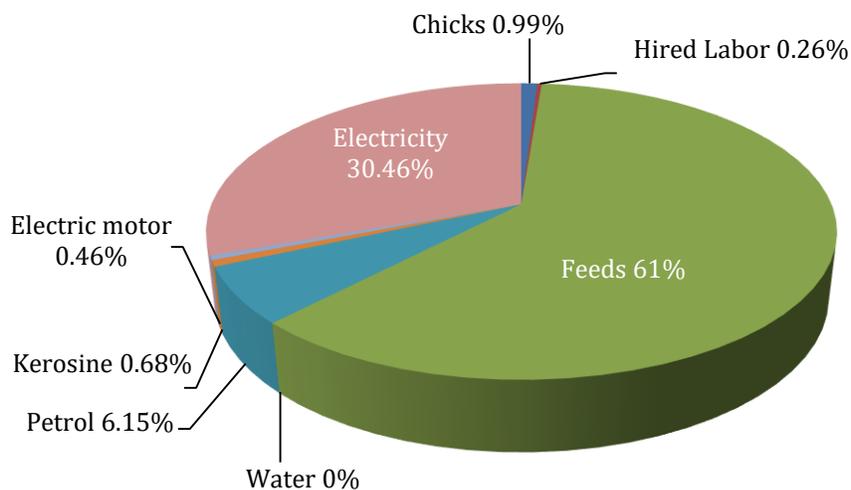


Figure 2. Total saving energy [1071.54MJ (500 birds)<sup>-1</sup>]

**Improvement of energy indices for broiler farms**

Comparison between energy indices in the actual and optimum energy use showed improvements of these indices (Table 9). By optimization of energy use, both energy ratio and energy productivity indicators can improve by 1.09% and 1.84%, respectively. Further, in optimum consumption of energy inputs, the net energy indicator by improvement of 1.66% would increase to 65,613.66 MJ (500 birds)<sup>-1</sup> *i.e.* the energy ratio, energy productivity, specific energy and net energy

were 1.83, 0.109 Kg MJ (500 birds)<sup>-1</sup>, 9.14 MJ (500 birds)<sup>-1</sup> and 64,542.12 MJ (500 birds)<sup>-1</sup>, respectively. They can be improved to 1.85, 0.111 Kg MJ (500 birds)<sup>-1</sup>; 9.02 MJ (500 birds)<sup>-1</sup> and 65,613.66 MJ (500 birds)<sup>-1</sup>, respectively Therefore, broiler production has had relatively high requirements for non-renewable energy resources and to certain extent feeds energy (renewable energy); its electrical energy requirement is high and need high amount of petrol fuel consumption in situation of power outage.

Table 9. Improvement of energy indices for broiler farms

| Items               | Unit                         | Quantity in Actual use | Quantity in Optimum use | Change (%) |
|---------------------|------------------------------|------------------------|-------------------------|------------|
| Energy ratio        | -                            | 1.83                   | 1.85                    | 1.09       |
| Energy productivity | Kg MJ <sup>-1</sup>          | 0.109                  | 0.111                   | 1.84       |
| Specific energy     | MJ Kg <sup>-1</sup>          | 9.14                   | 9.02                    | -1.3       |
| Net energy          | MJ (500 birds) <sup>-1</sup> | 64.542.12              | 65.613.66               | 1.66       |
| Total input energy  | MJ (500 birds) <sup>-1</sup> | 77.916.14              | 76.844.60               | -1.38      |

Source: Authors computation, 2015

In the case of feeds, farmers mainly don't have enough knowledge on more efficient input use and there is a common belief that increased use offered energy resource will increase output. These situations occur simply because the farmers mainly don't have enough knowledge on more efficient input use. Methods presented in this study

demonstrate how energy use efficiency in broiler production may improve by applying the operational management tools to assess the performance of farmers. On an average, considerable savings in energy inputs may be obtained by adopting the best practices of

benchmarking/high-performing DMUs in broiler production process.

Adoption of more energy-efficient poultry systems would help in energy conservation and better resource allocation. Strategies such as providing better extension and training programs for farmers and use of advanced technologies should be developed in order to increase the energy efficiency of broiler productions in the studied area. The farmers should be trained with regard to the optimal use of inputs, especially, electricity, petrol and feeds as well as employing the new production technologies. Therefore, agricultural institutes in the state have an important role in this case to establish the more energy efficient and environmentally-healthy broiler production systems in the studied area.

**GHG Emissions in Broiler Production**

GHG emission of efficient and inefficient DMUs was investigated to determine the role of energy

optimization in environmental condition of broiler production in the studied area (Table 10). The total GHG emission of broiler production was 1001.03 Kg CO<sub>2eq</sub>; the most amount of CO<sub>2</sub> emission was related to electricity with an estimated amount of 879.1 Kg CO<sub>2eq</sub> and followed by petrol. Therefore, energy consumption can be reduced by improving some management practices and technological changes in inefficient DMUs, subsequently; the emission of GHG can be decreased in the studied area.

Furthermore, results indicated that the optimum GHG emission can be reduced to the value of 981.44 Kg CO<sub>2eq</sub> (a 2% decrease). However, most reduction was observed in electricity (83.71%) and followed by petrol (12.68%). Using alternative renewable sources of energy for electricity generation such as wind, solar and biogas energy sources can lead to broiler production with less GHG.

Table 10. Amounts of GHG emission for actual and optimum

| <b>Inputs</b>      | <b>Actual<br/>[KgCO<sub>2</sub>(500 birds)<sup>-1</sup>]</b> | <b>Optimum<br/>[Kg CO<sub>2</sub> (500 birds)<sup>-1</sup>]</b> | <b>GHG reduction<br/>[Kg CO<sub>2</sub> (500 birds)<sup>-1</sup>]</b> |
|--------------------|--|---|---|
| Petrol             | 82.57  | 80.04   | 2.53 (12.68)  |
| Kerosene           | 25.35  | 24.98   | 0.37 (1.86)   |
| Electric motor     | 14.01  | 13.66   | 0.35 (1.75)   |
| Electricity        | 879.1  | 862.4   | 16.7 (83.71)  |
| Total GHG emission | 1001.03  | 981.44  | 19.95   |

Source: Computed from DEAP 2.1 computer print-out. Values in parenthesis are percentages.

**Conclusion**

Empirical evidence indicated that there were substantial production inefficiencies by farmers; such that, potential of 1.38% reduction in total energy input use may be achieved if all farmers operated efficiently and assuming no other constraints on this adjustment. In other words, the total energy input could be reduced by 1.38% without reducing the present output level by adopting study based recommendations. It was observed that the actual and optimum total GHG emission were 1001.03 Kg CO<sub>2eq</sub> and 981.95 Kg CO<sub>2eq</sub>, *i.e.* possibility of potential total GHG emission reduction by 19.95 Kg CO<sub>2eq</sub> if farmers comply with recommendations from this findings;

most reduction was observed in electricity (83.71%).

Moreover, results revealed that broiler production in the studied area showed a high sensitivity to non-renewable energy sources, which may result in both the environmental deterioration and rapid rate of depletion of these energetic resources. Therefore, policies should emphasize on the development of new technologies to substitute fossil fuels with renewable energy sources aiming at efficient use of energy and lowering the environmental footprints; limited fossil fuels sources implies that policy makers need to come up with best management in productivity

improvement of broiler production in the studied area.

Development of renewable energy usage technologies such as lightening systems using biogas, wind or solar power, using better management techniques, utilization of alternative sources of energy such as biogas, wind and solar energy are suggested to reduce the environmental footprints of energy inputs and to obtain sustainable broiler production systems. However, modern and well established scientific practices should be used to obtain higher technical efficiency in broiler production *viz.* having good knowledge of

broiler feeds consumption; specifically the quantity of required feeds per meat Kg (feed conversion ratio); capacity training of poultry farmers and processors to enable them cope with the present challenges of modern poultry farming and commercialization of the poultry sub-sector in the state in particular and the country in generally. Furthermore, losses at the farmers' level can be minimized through opening and strengthening of Agricultural Technology Information Centre (ATIC) in agricultural institution. Local level extension systems also needs to be strengthened for effective transfer of technology.

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